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Contribution of Life Cycle Cost analysis to design Sustainability in Construction

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Extended abstract

Jury

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October 2010

Chapter 1. Introduction and objectives

1.1 Introduction

The construction industry's main objective is the fabrication of a product that satisfies functional, security, durability, esthetic, economic and environmental requirements during its life cycle, in other words, a product that serves the intended function securely while also being durable, aesthetically pleasing, economically viable and that translates into the smallest environmental impact possible (Brito, 2007 e Pinheiro, 2006).

Sustainable construction is a way to responsibly create and manage a healthy constructed environment based upon the ecologic and resource efficiency principles, involving the consideration of a building's life cycle (Agenda 21, 1999).

Traditional construction is mostly concerned with cost, time and quality. Sustainable construction adds to those criteria the minimization of the use of scarce resources and environmental degradation, and also the creation of a healthy built environment (Kibert, 1994).

According to Godfaurd (2005), sustainable construction involves the consideration of the building's life cycle because the minimization and reduction of the impacts on nature depends on the building´s performance in all its stages. Following this line of thinking, life cycle cost analysis should replace the sole consideration of the initial investment cost.

Gupta (1983) mentions that approximately 75% of the life cycle cost of an asset is related to the operation and maintenance stages, which makes the consideration of life cycle cost when analyzing an asset unavoidable.

Of all the building's components, the equipments have been the focus of the LCC analysis, leaving other constructive aspects of the building, such as structural and finishing aspects, less studied.

The façade is responsible for a significant part of a building's construction and maintenance costs, being object of major maintenance needs, because it protects the inner space against external threats. It also contributes to the acoustic and thermal performance of the building and, as such, to the energetic costs of the building. Given its importance, the façade was selected to be the focus of this dissertation.

1.2 Objectives

This dissertation is based upon the hypothesis that it is possible to apply the LCC analysis in search of sustainability. For that to be possible, this dissertation has specific objectives which are the following:

- ✓ analyze the LCC approach applied to sustainability;
- ✓ investigate which solutions and activities are associated with sustainable construction costs;
- ✓ appraise the possibility of application;
- ✓ assess its usefulness, limitations and perspectives.

Chapter 2. State of the Art

2.1 What is LCC?

Life Cycle Costing is a methodology for systematic economic evaluation of the life cycle costs over a period of analysis, as defined in the agreed scoping (ISO 15686-5, 2006). In other words, it is an economic methodology for selecting the most cost-effective design alternative over a particular time frame, including construction, operation, maintenance, replacement, rehabilitation costs and also residual value.

According to the Royal Institute of Chartered Surveyors (1983), the objectives of LCC are:

- to enable investment options to be more effectively evaluated;
- to consider the impact of all costs rather than only initial capital costs;
- to assist in the effective management of completed buildings and projects;
- to facilitate choice between competing alternatives.

2.2 Costs

In approaches such as LCC, it becomes necessary to divide costs into groups that can be defined and estimated separately, making it easier to quantify the costs and compare different alternatives.

The process of LCC analysis depends mainly on identifying all relevant costs which occur over a specified period of study. If the analysis period is the asset's life cycle, those costs include all possible costs from the initial acquisition costs to the end of life costs.

In that case, a possible cost breakdown structure would be (Langdon, 2007 based on ISO 15686-5, 2006) the one shown in Table 1.

2.3 Service life and maintenance

Service life is the period of time after installation during which a building or its parts meets or exceeds the performance requirements (ISO 15686-1, 2000).

The service life of any building is governed by a number and coincidence of several different factors. These include the sufficiency of the design, constructional details and the methods used for its construction. It is also dependent upon the way that the building is used and the maintenance policies and practice undertaken during its life (Ashworth, 1996).

Therefore, the prediction of a building's service life is fundamental to its LCC analysis and, as such, it becomes necessary to study the specific requirements to be filled during that time.

BSI BS 3811 (1984) defines **maintenance** as a combination of any actions carried out to retain an item in, or restore it to an acceptable condition.

The maintenance strategies are divided in reactive maintenance and proactive maintenance, which in turn is divided in preventive maintenance, predictive maintenance and improvement maintenance.

The maintenance strategy applied in this dissertation is the preventive maintenance plan which consists on the performing of maintenance activities according to an operation plan with fixed periodicities and costs, in an attempt to avoid extra work needs and subsequent added costs.

Table 1 - Cost Breakdown Structure (Langdon, 2007)

Acquisition – non-construction costs	Acquisition – design and construction	Operation	Maintenance	Rehabilitation	End of life/ disposal/hand-back	Income
Site (lease/ purchase of land and/ or existing building(s) /asset(s), including related fees and local taxes)	Professional services (project management, architecture, structural/ civil/ environmental engineering, cost and value management)	Facilities management (cleaning, security, waste management)	Maintenance management (inspections, contract management)	Adaptation (evacuation, works, re-commissioning, fit-out)	Final condition inspection including fees	Sales of land, interests in assets, salvaged materials
Finance (interest or cost of money; wider economic impacts)	Site clearance, temporary works	Rates/local taxes, land charges	Minor repairs/ replacements/ renewals	Major replacement/ renewal/ refurbishment (evacuation, works, re-commissioning, fit-out)	Restoration/ reinstatement (as required by lease/contract)	Grants, tax allowances
Client's in-house resources (property/ project management, administration/overheads)	Construction (infrastructure, structure, envelope, services, fitting out, commissioning, handover)	Regulatory costs (fire, access inspections)	Loss of facility / business opportunity costs during downtime	Loss of facility / business opportunity costs during downtime	De-commissioning	Third party income (rents, service charges)
Professional advice (planning, legal, preparing brief, sustainability)	Fixtures, fittings, Furnishings	Energy (heating, cooling, small power, lighting, internal transport (lifts))	Grounds maintenance		Demolition, disposal, site clean-up	
	Landscaping, external works	Utilities (water, sewerage, telephone)	Redecoration			
		Rent	Cleaning			
		Insurances				

2.4 Basic steps

Several authors propose possible steps to generate an effective LCC analysis such as King County LCCA Guide (n.d.), Langdon (2007) and Kelly and Hunter (2007). However, in every set of steps the same essential points can be identified.

According to Kelly and Hunter (2007), Ruegg et al (1980) and Flanagan and Jewell (2005) there are five basic steps to making decisions about options:

1. Identify project objectives, options and constraints;
2. Establish basic assumptions with respect to the period of study, the discount rate, the level of comprehensiveness, data requirements, cash flows and inflation;
3. Compile data;
4. Discount cash flows to a comparable time base;
5. Compute total life cycle costs, compare options and make decisions.

2.5 Cost evaluation method

There are many different methods to evaluate the life cycle cost of an asset. As the primary objective of LCC is to facilitate the effective choice between a number of competing alternatives, the most used method is the Net Present Value (NPV).

The NPV of an alternative is the summation of all costs occurred during the period of study of the life cycle of the asset, converted to their present value (using a discount rate) so they are comparable. The alternative with the highest NPV is the most cost effective choice (King County LCCA Guide, n.d.).

2.6 Potential LCC limitations, types and sources of information and risk assessment techniques

Despite the advantages that the LCC methodology brings to sustainable construction, it has found **limited application** so far.

According to Bull (1993), the capital cost of construction and the operating cost are almost always supported by different entities and, because of that, the construction entities do not feel encouraged to raise their initial investment in order to reduce another entities' operating and maintenance costs, which does not promote the LCC application.

Bull (1993) also pointed out that the major obstacle to the LCC analysis' implementation is the lack of appropriate, relevant and reliable information and data upon which to base the analysis. In addition, costs of data collection are enormous, which takes a long time to collect (Ferry e Flanagan, 1991).

Ferry e Flanagan (1991) also mention that another difficulty is the need to be able to forecast, a long way ahead in time, many factors such as life cycles, future operating and maintenance costs, and discount and inflation rates.

Glush e Baumann (2000) referred to some other limitations such as: LCC fails to handle decisions under uncertainty; fails to handle irreversible decisions; neglects items without owner, such as the environment; over-simplifies environmental problems into a monetary dimension; underrates future environmental costs; suffers from poor availability and reliability of data; relies on many estimated variables due to the complexity of the building and the building process; results are biased towards the decision maker's personal values; may restrain learning if to mechanically used; is beset with conceptual confusion due to many similar LCC-oriented tools and inconsistent life cycles.

On the **types of information** matter, Flanagan & Norman (1993) highlighted the data requirements in successfully implementing a life-cycle costing methodology: estimates of initial and running costs of elemental life-cycles, discount rates, inflation indices, periods of occupancy, energy consumption, cleaning and the like.

According to Schade (2007), there are three main **sources of data** for LCC purposes:

- data from the manufacturers, suppliers, contractors and testing specialists;
- historical data;
- data from modelling techniques.

LCC deals with the future and, as the future is unknown, there is a need to be able to forecast a long way ahead in time, many factors such as life cycles, future operating and maintenance costs, and discount and inflation rates. This difficulty is worsened by the difficulty in obtaining the appropriate level of information and data. Therefore, the treatment of uncertainty in information and data becomes crucial to the implementation of LCC (Kishk et al., 2003).

To deal with these problems there are various **risk assessment techniques**. Nowadays, the most used ones are Sensitivity Analysis (deterministic approach), Monte Carlo Simulation (probabilistic approach) and the Fuzzy Set Theory.

2.7 What has been done in terms of LCC?

Although there are no formal methodologies or legislation supporting LCC in most european countries, there are standards, guidelines and other LCC documents which attempt to encourage its implementation, as it is the example of: "TG4: Life cycle costs in construction" (TG4, 2003), "ISO 15686-5: Building and constructed assets – Service life planning" (ISO, 2006), "NS 3454: Life cycle cost for building and civil engineering work – Principles and classification" (NS 3454, 2000), "Procurement guide 7: Whole-life costing and cost management" (PG7, 2007), "Life cycle costing as a contribution to sustainable construction: a common methodology – literature review" (Langdon, 2007a) e "Life cycle costing as a contribution to sustainable construction: a common methodology" (Langdon, 2007).

In Portugal, the usual construction process is still the traditional one, i.e., only taking in consideration project and construction costs. Since this kind of approach does not take into account all the other building's life cycle stages, it does not fit into the lines of the LCC methodology.

LCC analysis has been applied in Portuguese universities' maintenance studies, as it is the example of Flores (2002), Falorca (2004) and Gomes (2007). However, most of these studies only take into account the construction and maintenance stages, not considering the remaining stages and associated costs.

There are signs of growing concern with the maintenance and rehabilitation stages, in which economic viability is an important and decisive component.

2.8 LCC and sustainability

According to Kibert *et al.* (2002), sustainable construction considers all the life cycle stages of the built environment: planning, design, construction, operation and deconstruction/demolition.

To Kibert *et al.* (2002), sustainability in the construction sector is dependent upon a deep change in the way resources are consumed, changing from non renewable energy sources to renewable ones, from high levels of residue production to high levels of reutilization and recycling, and from products based in the lowest initial cost to products based on the total cost taking into account its life cycle, especially when applied to the residue and emission generation through the industrial process that supports the construction sector.

It should be noted that in the transition from the 2005 to the 2009 version, system LiderA included LCC as a new parameter (C40 criteria), though, in reality, its application is only focused in high investments that can bring interesting returns in the following years, as the systematic attainment of all the costs bares a certain degree of difficulty.

As such, LCC is one of the components to ensure in the search for sustainability, which is confirmed by the choice of system LiderA to include a criteria that applies the LCC methodology.

Chapter 3. Solutions and LCC

3.1 Initial considerations

During the research of the components and solutions for the building's façade, it is necessary to define certain parameters, such as the location of the building – Lisbon –, its size – three floors and at least another one underground –, and the study period – 50 years (a building's approximate service life). The case study, presented in chapter 4, fits these parameters.

3.2 General requirements

The Construction Products Directive 89/106/CE establishes the conditions of a product's free movement throughout the community, bearing the CE mark. This product quality control system defines six essential requirements: mechanical resistance and stability; safety in case of fire; hygiene, health and the environment; safety in use; protection against noise; energy economy and beat retention.

Such requirements must, subject to normal maintenance, be satisfied for an economically reasonable working life.

3.3 Façade's constructive solutions

The study of the façade's constructive solutions starts with the consideration of all the possible solutions. However, some solutions are ruled out for different reasons, as it is the example of the loam work, because it does not fulfill the needed requirements, or the foto-energetic glazing, because it was not possible to obtain its costs or quantify its benefits.

The hall rendering options considered are: cement rendering; paint; ceramic lining and natural stone lining.

The insulation options considered are: XPS; cork and the ETICS system with XPS or cork.

The masonry options considered are: brickwork; lightweight concrete; normal concrete and autoclaved aerated concrete.

The types of frame considered are: aluminum without thermal cut; aluminum with thermal cut and PVC.

The types of glazing considered are: simple glazing; double glazing with air inside; double glazing with argon inside and double low-e glazing.

The shading options considered are: PVC external blinds; aluminum external blinds and aluminum shutters.

3.4 Preventive maintenance plans

Table 2 presents the preventive maintenance plans considered in this dissertation.

Table 2 - Preventive maintenance plans

Cement rendering	10% reparation and cleaning every 5 years Total substitution on the 30th year
Natural stone lining	35% reparation every 20 years Cleaning every 5 years
Ceramic lining	10% reparation every 5 years
ETICS	Paint every 5 years 35% reparation every 20 years Total substitution on the 40th year
Paint	Total substitution every 5 years
Frames and glazing	Cleaning every 6 months Tuning and lubrification of fittings every year Total substitution of sealing materials every 10 years Total substitution of fittings every 20 years Total substitution of frames every 30 to 36 years
Metallic guard	35% reparation of welds every 20 years Sand and paint every 10 years Total substitution on the 34th year
PVC external blinds	Annual cleaning Reparation of broken blind strips every 5 years Total substitution of tape every 2 years
Aluminum external blinds	Annual cleaning Total substitution of tape every 2 years
Aluminum shutters	Annual cleaning Paint every 10 years

3.5 Operation and demolition or rehabilitation

During the operation stage, the façade contributes to the acoustic and thermal performance of the building, as well as to its architectonic and landscaping beauty. However, in terms of operational quantifiable costs, the façade only influences the energetic costs of a building since it contributes to its energetic needs. These energetic needs are calculated according to the national law that transposes the Energy Performance Building Directive (Decreto-lei nº80/2006 de 4 de Abril – Regulamento das Características do Comportamento Térmico dos Edifícios (RCCTE)).

At the end of the building's life cycle there are several options: undifferentiated demolition followed by backfilling, selective demolition and recycling or reutilization of the components, and rehabilitation. The final decision is based essentially on the associated costs of each option and also the decision maker's judgment and sense of responsibility towards the environment.

Chapter 4. Case study

4.1 Case study's description

The presented LCC methodology approach is being tested on a model building from a project called HEXA (developed by the Sustainable team of System LiderA), which is a six floor sustainable residential building (except for the ground floor which has commercial purposes) that applies the LiderA criteria to all its components.

The objective is to compare different solutions and find out which ones are best suited to the intended life span of the building and its costs by taking LiderA's criteria into account.

4.2 Global costs and main assumptions

The construction and maintenance costs used in this dissertation are mainly obtained through market surveys, contacting construction entities, as well as construction material suppliers'.

The operation costs are obtained by multiplying the energetic needs of an apartment, in a middle floor, in kWh by the kWh price.

No demolition or rehabilitation costs are considered as they do not occur within the study period.

Some of the main assumptions are:

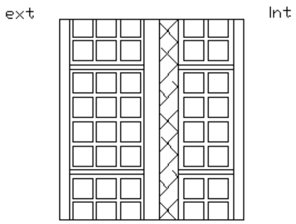
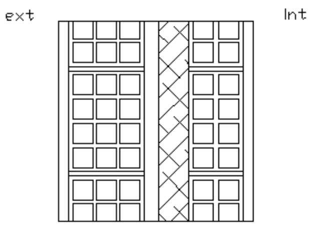
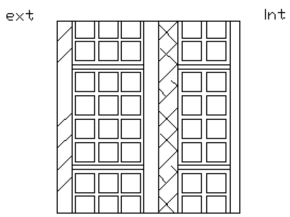
- The method of cost evaluation considered is NPV;
- The discount rate applied in this dissertation is 6%.

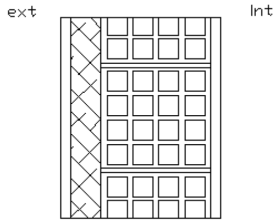
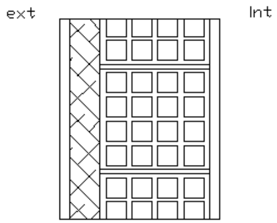
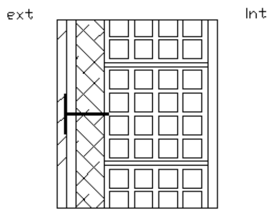
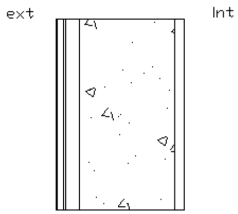
4.3 Selection/comparison of the solutions

This part of the dissertation starts with the study of the different masonry options which results in the selection of the brickwork option because it is the one found more suitable in terms of performance and cost.

After that, the wall solutions presented in Table 3 are analyzed.

Table 3 – Wall solutions

Solution	Design	Component description	CC (€/m²)	MC (€/m²)	U (W/m²ºC)	CC + MC (€/m²)
P1		External paint External cement rendering 2 cm Double brick wall 15+11 cm XPS insulation 4 cm in the air space Internal cement rendering 2 cm Internal paint	58	41	0,47	99
P2		External paint External cement rendering 2 cm Double brick wall 15+11 cm cork insulation 6 cm in the air space Internal cement rendering 2 cm Internal paint	63	41	0,42	104
P3		External natural stone lining 3 cm Double brick wall 15+11 cm XPS insulation 4 cm in the air space Internal cement rendering 2 cm Internal paint	119	32	0,47	151

Solution	Design	Component description	CC (€/m²)	MC (€/m²)	U (W/m²ºC)	CC + MC (€/m²)
P4		External ETICS system with EPS 6 cm and reinforced coat Brick wall 22 cm Internal cement rendering 2 cm Internal paint	62	36	0,45	98
P5		External ETICS system with cork 6 cm and reinforced coat Brick wall 22 cm Internal cement rendering 2 cm Internal paint	69	37	0,47	106
P6		External ETICS system with EPS 6 cm and natural stone lining Brick wall 22 cm Internal cement rendering 2 cm Internal paint	124	40	0,50	164
P7		Aluminum frame with double glazing Air space Normal concrete wall 20 cm Internal cement rendering 2 cm and paint (Tromb wall)	160	56	1,72	216

where CC – Construction Cost and MC – Maintenance Cost.

Solution P1 is the solution with the lowest construction cost, while solution P3 is the one with the lowest maintenance cost. The solution that presents the lowest U coefficient is solution P2.

The advantages of the LCC analysis can already be confirmed in Table 2, when comparing solutions P1 and P4, even without taking into account its energetic component. Even though solution P1 has the lowest construction cost, P4 presents a maintenance cost low enough to grant solution P4 the lowest construction plus maintenance cost and make it the best choice.

Solutions that apply cork insulation are considered as more sustainable (because they use elements of natural origin, reducing the impacts of the product) than the solutions that apply XPS or EPS insulation. It is also considered that the bigger the contribution of the wall solution to the energetic costs reduction, the more sustainable the solution is.

In terms of frames, the different options are compared and the one considered to be the best choice is the aluminum with thermal cut frame.

For the aluminum with thermal cut frame, several options of glazing are tested. All the options are viable except for the simple glazing which does not perform as required.

Then, the shading options are compared and the one considered to be the most suitable choice is the PVC external blind.

Taking all of the studied components into account, four façade solutions are formed to study more thoroughly: reference solution, improved solution, high performance solution 1 and high performance solution 2 presented in Tables 4 to 7.

Table 4 – Constitution of the reference solution

Reference Solution
Double brick wall 15+11 cm with 4 cm of XPS in the air space, cement rendered and painted on both sides, except for the kitchen wall
Double brick wall 15+11 cm with 4 cm of XPS in the air space, cement rendered and painted on the exterior side and with ceramic lining on the interior side of the kitchen, located north
Aluminum with thermal cut frame with double glazing 4/12/4 mm and PVC external blind
Metallic guard in L shape on the south balcony
Sill tiles in free stone

Table 5 – Constitution of the improved solution

Improved solution
Brick wall 22 cm with ETICS system (with EPS 6cm) on the north and south walls, cement rendered and painted internally, except for the kitchen wall
Brick wall 22 cm with ETICS system (with EPS 6cm) with internal ceramic lining on the kitchen wall, located north
Double brick wall 15+11 cm with 4 cm of XPS in the air space, cement rendered and painted on both sides on the east wall
Aluminum with thermal cut frame with double glazing 4/12/4 mm and PVC external blind
Metallic guard in L shape on the south balcony
Sill tiles in free stone

Table 6 – Constitution of the high performance solution 1

High performance solution 1
Tromb wall on part of the south wall
Brick wall 22 cm with ETICS system (with cork 6cm) on the north and south walls, cement rendered and painted internally, except for the kitchen wall and the Tromb wall
Brick wall 22 cm with ETICS system (with cork 6 cm) with internal ceramic lining on the kitchen wall, located north
Double brick wall 15+11 cm with 4 cm of cork in the air space, cement rendered and painted on both sides on the east wall
Aluminum with thermal cut frame with double low-e glazing 4/16/4 mm and PVC external blind
Metallic guard in L shape on the south balcony
Sill tiles in free stone

Table 7 – Constitution of the high performance solution 2

High performance solution 2
Tromb wall on part of the south wall
Brick wall 22 cm with ETICS system (with cork 6cm) on the north and south walls, cement rendered and painted internally, except for the kitchen wall and the Tromb wall
Brick wall 22 cm with ETICS system (with cork 6 cm) with internal ceramic lining on the kitchen wall, located north
Double brick wall 15+11 cm with 4 cm of cork in the air space, cement rendered and painted on both sides on the east wall
Aluminum with thermal cut frame with double glazing 4/12/4 mm and PVC external blind
Metallic guard in L shape on the south balcony
Sill tiles in free stone

Table 8 presents the life cycle costs of the apartment's façade for a study period of 50 years.

Table 8 – Life cycle costs of the apartment's façade for a study period of 50 years

Solution	CC (€)	MC (€)	Energetic needs (kWh/year)	EC (€)	NPV (€)
Reference	13021	5557	418	758	19336
Improved	13293	5332	382	693	19318
High Performance 1	15429	5623	374	678	21730
High Performance 2	15173	5591	371	672	21436

where CC - Construction Costs, MC - Maintenance Costs and EC - Energetic Costs.

The reference solution presents the lowest construction cost. However, the solution that presents the lowest maintenance cost is the improved solution, and the one with lowest energetic cost is the high performance 2 solution. Globally, the best solution is the improved solution.

The comparison of the reference solution with the improved solution shows that, although the improved solution presents a significantly higher construction cost, the reductions in energetic consumption of the apartment and maintenance needs in the study period that this solution presents are enough to compensate the increase in initial cost, making evident the LCC analysis potential.

Comparing the high performance solution 1 with the high performance solution 2, it becomes clear that not always the application of a window (frame plus glazing) solution with a lower U coefficient and a lower solar factor is justified. That's due to the window's solar orientation as well as its area, i.e., if the window's distribution and/or its area (in comparison with the wall area) was different, it would be possible for the high performance 1 solution to, globally, be a better solution than the high performance 2 solution.

The comparison of the reference solution with the high performance 2 solution shows that, in this case, the reduction of energetic consumption is not enough to compensate the increase of construction and maintenance costs.

The NPV variation between the improved solution and the reference solution is approximately 0,1%, i.e., is reduced. However, the NPV variation between the improved solution and the high performance 1 solution is approximately 12,5%.

Having all of the studied aspects in mind, it can be concluded that the best solution in terms of initial investment costs may not be the best solution when analyzing all its life cycle costs, as is the example of the reference solution and improved solution case, which makes it important to perform this type of LCC analysis.

Chapter 5. Sensitivity analysis

5.1 Sensitivity analysis

Among the variables studied during the sensitivity analysis, those which the results are worth mentioning are: reference solution without maintenance, variation of the study period and variation of the discount rate.

5.1.1 Reference solution without maintenance

In order to verify the effect of maintenance in this study, calculations are made to compare the reference solution with a reference solution without maintenance. The results are presented in Table 9.

Table 9 – Life cycle costs of the apartment's façade with and without maintenance

Solution	CC (€)	MC/replacement (€)	Energetic needs (kWh/year)	EC (€)	NPV (€)
Reference	13021	5557	418	758	19336
Reference without maintenance	13021	6349	418	758	20129

Not performing any maintenance activity induces an increase of 4,1% in the NPV of the Reference solution, which proves that, even though maintenance activities during the life cycle bare high costs, they are necessary to improve the building's performance and service life as well as to reduce its life cycle costs.

5.1.2 Variation of the study period

The longer the study period is, the bigger is the uncertainty of the LCC analysis' parameters. Thus, calculations are made for a 25 year study period. The results are presented in Table 10.

Table 10 – Life cycle costs of the apartment's façade for a study period of 25 years

Solution	CC (€)	MC (€)	Energetic Needs (kWh/year)	EC (€)	NPV (€)
Reference	13021	3745	418	626	17392
Improved	13293	3610	382	562	17465
High Performance 1	15429	3632	374	550	19611
High Performance 2	15173	3632	371	545	19350

For a study period of 25 years, the solution that presents the lowest life cycle costs is no longer the improved solution but the reference solution.

This result indicates that the study period bears great importance in the LCC analysis and, as such, must be carefully chosen.

5.1.3 Variation of the discount rate

In order to verify the effect of the discount rate in this study, calculations are made for a discount rate of 2%. The results are presented in Table 11.

Table 11 - Life cycle costs of the apartment's façade for a discount rate of 2%

Solution	CC (€)	MC (€)	Energetic Needs (kWh/year)	EC (€)	NPV (€)
Reference	13021	13421	418	1512	27954
Improved	13293	13066	382	1381	27740
High Performance 1	15429	14032	374	1352	30813
High Performance 2	15173	13907	371	1340	30420

For a discount rate of 2%, the solution that presents the lowest life cycle costs is the same that it was for a discount rate of 6%, the improved solution.

On the other hand, there is a 42 to 45% increase of the solutions' NPV due to the increase of the maintenance and energetic costs contribution to the life cycle costs.

The main conclusion is that the lower the discount rate applied, the bigger the influence of future costs in the life cycle.

5.2 Main limitations

Despite the advantages that the LCC methodology brings to sustainable construction, it has found limited application so far.

The main problem of the LCC analysis is the lack of reliable information and the difficulty in forecasting over a long period of time factors such as component life cycle and performance, future operating and maintenance plans and costs and discount rates.

The quantity of required data enormous and complex, and the time needed for its collection is extensive.

All costs are variable, depending on who the supplier is, the quantity and quality needed and the delivery location, among others.

In addition to that, many innovative components and techniques' costs and performances are not yet available, making their integration in this study an impossibility.

The fact that the benefits of passive solutions, such as the Tromb wall, could not be properly taken into account in the RCCTE calculation, made it difficult to accurately compare all of the solutions.

Finally, the LCC analysis does not consider intangible aspects in terms of costs, such as the user's comfort or the value of a building for being "greener", i.e., for not causing as much environmental impact as other buildings, or even the being or not recycled/recyclable and/or natural in origin of a material or component.

Chapter 6. Conclusions

The LCC approach has been applied to construction, though still in a reduced number of cases. It presents itself as way to reach the lowest possible cost of sustainable buildings in their life cycle, contributing to balance environmental and economic aspects as a way to achieve sustainability.

As such, this dissertation set out to apply the life cycle cost analysis to a façade, as it is responsible for a significant amount of a building's life cycle costs. The case study is a model building from a project called HEXA which applies the LiderA criteria to all its components.

For the façade's several components, a market survey of construction and maintenance costs was conducted, and its functional requirements, service lives, pathologies, maintenance plans and performances were analyzed, as well as all the remaining information needed for the life cycle costs analysis. Taking into account all the gathered information, the different façade components were separately analyzed. After that four façade solutions were formed and analyzed – reference solution, improved solution, high performance 1 solution and high performance 2 solution.

The solution which presented the lowest construction cost was the reference solution and the one with the lowest life cycle costs was the improved solution, presenting lower maintenance and energetic costs than the previous solution.

The NPV variation between the improved solution and the reference solution is approximately 0,1%, i.e., is reduced. However, the NPV variation between the improved solution and the high performance 1 solution is approximately 12,5%.

The sensitivity analysis demonstrated the importance of the implementation of maintenance activities as well as the choice of an appropriate study period and discount rate. Not performing maintenance activities, introduces a 4,1% raise to the reference solution's life cycle costs. For a 50 year study period the solution with the lowest life cycle costs was the improved solution, whereas for a 25 year period it was the reference solution. The lower the discount rate applied, the bigger the influence of future costs in the life cycle.

The studied façade cases demonstrated that the best choice in terms of initial investment costs may not be the best choice when a LCC analysis is performed, as it is the case of the improved solution vs. reference solution, which makes it relevant to include the LCC analysis in the process.

Therefore, if the costs are analyzed in the life cycle, and not only in terms of investment cost, it is understandable that the application of the sustainable principles to the construction industry without ignoring the economic component is a reachable reality and of extreme importance.

Finally, another important aspect is that this kind of approach still needs further research to overcome all its limitations and also requires a valid cost data base. It is essential to gather information and create a solid database about maintenance, product performance (durability and other aspects) and costs, so that analysis can be made with less uncertainty and more precisely applied.

References

Agenda 21. [1999]. “Agenda 21 on sustainable construction”. CIB. Report Publication 237.

Ashworth, A. [1996]. “Cobra 1996 - Assessing the life expectancies of buildings and their components in life cycle costing”. RICS, UK.

Brito, J. [2007]. “Folhas da cadeira de Tecnologia da Construção de Edifícios”. Tecnologia da Construção de Edifícios. Instituto Superior Técnico – Universidade Técnica de Lisboa.

BSI BS3811. [1984]. “Glossary of maintenance management terms in tero-technology”.

Bull J. W. [1993]. “Life cycle costing for construction”. Blackie Academic & Professional. Glasgow.

Falorca, J. [2004]. “Modelo para plano de inspecção e manutenção em edifícios correntes”. Dissertação de Mestrado em Engenharia Civil. Faculdade de Ciências e Tecnologia – Universidade de Coimbra.

Ferry, D. e Flanagan, R. [1991]. “Life Cycle Costing - A radical approach”. CIRIA Report 122. London.

Flanagan, R e Norman, G. [1993]. “Risk management and construction”, Blackwell Scientific Publications.

Flanagan R. e Jewel C. [2005]. “Whole Life Appraisal for construction”, Blackwell, Oxford.

Flores, I. [2002]. “Estratégias de manutenção – Elementos da envolvente de edifícios correntes”. Dissertação de Mestrado em Construção. Instituto Superior Técnico – Universidade Técnica de Lisboa.

Gluch, P. e Baumann, H. [2000]. “The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision making”. Chalmers University of Technology, Goteborg, Sweden.

Godfaurd, J., Clements-Croome, D., e Jeronimidis, G. [2005]. “Sustainable building solutions: A review of lessons from the natural world”. Building and Environment. pp. 319-328.

Gomes, J. [2007]. “Sistemas de caixilharia de PVC: Contributo para a qualidade e sustentabilidade da construção”. Dissertação de Mestrado em Construção. Instituto Superior Técnico – Universidade Técnica de Lisboa.

Gupta, Y. P. [1983]. “Life cycle cost models and associated uncertainties”. Electronics Systems Effectiveness and Life Cycle Costing, NATO ASI Series, v. F, pp. 535-549.

ISO 15686-1. [2000]. “Buildings – Service life planning – Part 1: General principles”. International Organization for Standardization.

ISO 15686-5. [2006]. “Buildings – Service life planning – Part 5: Life cycle costing”. International Organization for Standardization.

Kelly J e Hunter K [2007]. “Cobra 2007 – A Standard Approach to the Whole Life Costing of Small Scale”. Sustainable Energy Generation and Design Solutions. Georgia University of Technology. Atlanta,Georgia. Paper No. 38.

Kibert, C. [1994]. “Establishing principles and a model for sustainable construction”. In Proceedings of the First International Conference on Sustainable Construction, ed.C.J. Kibert. Tampa, FL. CIB TG 16.

Kibert, C. J., Sendzimir, J., e Bradley, G. [2002]. "Construction ecology: nature as the basis for green buildings".

King County LCCA Guide [s.d.]. "King County LCCA Guide".

Kishk, M., Al-Hajj, A., Pollock, R., Aouad, G., Bakis, N. e Sun, M. [2003]. "Whole life costing in construction: a state of the art review". RICS Foundation.

Langdon [2007]. "Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology". Davis Langdon Management Consulting.

Langdon [2007a]. "Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology – literature review". Davis Langdon Management Consulting.

NS 3454. [2000]. Norwegian Standard 3454.

Pinheiro, M. [2006]. "Ambiente e construção sustentável", Instituto do Ambiente (Conselho Cientifico: Correia, F. N.; Branco, F., Guedes, M.). Lisboa.

PG7. [2007]. "Procurement guide 7: Whole-life costing and cost management". Office of Government Commerce. London.

Schade, J. [2007]. "Life cycle cost calculation models for buildings". Lulea University of Technology. Lulea, Sweden.

TG4. [2003]. "Task Group 4: Life cycle costs in construction – final report".